RADIATION MEASUREMENT ACCURACY OF Z-DYNAMIC HOHLRAUMS *

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Abstract

As calculational capabilities mature the data accuracy requirements become more stringent. Typical Z-pinch power measurements use multiple sets of filtered X-Ray Diodes[1] (XRD) to provide temporally and spectrally resolved information on the pinch performance within a +/- 12% error bar. Integrated power measurements are provided by Ni-foil bolometers[2] with +/- 10% accuracy

Los Alamos has performed 75 experiments at the Sandia Z-machine in which both XRD's and bolometers viewed a Trad >150 eV radiation source. Comparison between the diagnostics revealed puzzling discrepancies of up to a factor of two.

Closer examination of the XRD's and bolometers reveals fabrication, material properties, calibration, and analysis subtleties that may account for the differences.

Assumptions of constant Cp and linear resistance changes are invalid if the bolometer heating is too great. Also if the element is heated to its Curie temperature non-linear behavior occurs. Furthermore, the thin film properties of the nickel bolometer element can vary greatly from the bulk material properties.

For the XRD's, the photoemissive surface properties of the cathodes can be altered as they are used in a high x-ray fluence and dirty vacuum environment. The x-ray filters can also be damaged from x-ray heating and blast debris. How filters are characterized and calibrated can also be an issue.

We present the methods used to construct, calibrate the detectors, field the experiment, and analyze data in order to quantify the error bars on the measurements.

I. THE Z-MACHINE

Sandia National Laboratories Z-machine pulsed power facility [1] consists of 36 Marx modules driving 36 pulse-forming lines which converge onto magnetically insulated transmission lines connected to a small diameter wire array. The Marx generators are charged to 90 kV and when fired dump a 5 MV pulse into the pulse forming lines. The pulse lines convert the long Marx pulses into short electrical pulses and synchronize the pulses to arrive simultaneously at a wire array target. The converging electrical pulses reach a peak current of 20 MA in the wire array which then implodes radially due to the **J x B** forces on the wires. When the wire plasma collides on axis, its kinetic energy is converted to heat producing bolometric temperatures of about 200 eV. The 11.4 MJ of stored electrical energy in the Marx modules is converted to about 2 MJ of radiation with peak radiation power in the 200 TW range.

Alternatively, a low density foam cylinder can be placed on axis for a Dynamic Hohlraum.

II. DYNAMIC HOHLRAUM

The Dynamic Hohlraum [2] used in our experiments consists of a 5 mm diameter x 9.5 mm x 14 mg/cc TPX foam cylinder surrounded by a 20 mm diameter x 7.5 micron x 120 tungsten wire array, which is surrounded by a 40 mm diameter x 7.5 micron x 240 tungsten wire array, all enclosed in a 50 mm diameter current return can. When the nested arrays collapse onto the cylinder the strongly shocked foam produces a radiation pulse with a peak temperature up to 250 eV which is trapped inside the foam. Experiment packages are coupled to the radiation source at the top end of the foam cylinder. The bottom end of the cylinder is viewed with XRD’s, bolometers, spectrometers, and x-ray cameras to monitor the z-pinch performance.

III. PHOTOCATHODE X-RAY DIODE

A Los Alamos designed photocathode type XRD is shown in Figure 1 . The design is compatible with the detector [3] used at the Z-machine. The XRD is assembled inside a type-N coaxial cable connector. Small 1.5 mm holes are drilled in the side of the connector to vent trapped gas pockets in the assembly. This particular XRD uses a commercially available electron microscope vitreous-carbon planchet as the photocathode. Etched nickel mesh mounted upon a standard size stainless steel washer provides the anode field shaping electrode. A standard size Teflon washer insulates the cathode from the connector housing. Two layers of 0.25 mm Teflon sheet separate the anode mesh from the cathode. Two layers with different inside diameters are used to provide

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14. ABSTRACT

As calculational capabilities mature the data accuracy requirements become more stringent. Typical Z-pinch power measurements use multiple sets of filtered X-Ray Diodes1 (XRD) to provide temporally and spectrally resolved information on the pinch performance within a +/- 12% error bar. Integrated power measurements are provided by Ni-foil bolometers2 with +/- 10% accuracy Los Alamos has performed 75 experiments at the Sandia Z-machine in which both XRD's and bolometers viewed a Trad >150 eV radiation source. Comparison between the diagnostics revealed puzzling discrepancies of up to a factor of two. Closer examination of the XRD's and bolometers reveals fabrication, material properties, calibration, and analysis subtleties that may account for the differences. Assumptions of constant Cp and linear resistance changes are invalid if the bolometer heating is too great. Also if the element is heated to its Curie temperature nonlinear behavior occurs. Furthermore, the thin film properties of the nickel bolometer element can vary greatly from the bulk material properties. For the XRD's, the photoemissive surface properties of the cathodes can be altered as they are used in a high xray fluence and dirty vacuum environment. The x-ray filters can also be damaged from x-ray heating and blast debris. How filters are characterized and calibrated can also be an issue. We present the methods used to construct, calibrate the detectors, field the experiment, and analyze data in order to quantify the error bars on the measurements.

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a longer surface track length than a single 0.5mm sheet does. The 0.25 mm washers are punched using a coaxial punch tool. The planchet is attached to a brass pedestal using an electrically conductive silver-loaded epoxy. Only the pedestal requires a machine lathe for fabrication, all other operations can be performed using simple hand tools. The pedestal is soldered to the contact pin provided with the cable connector assembly.

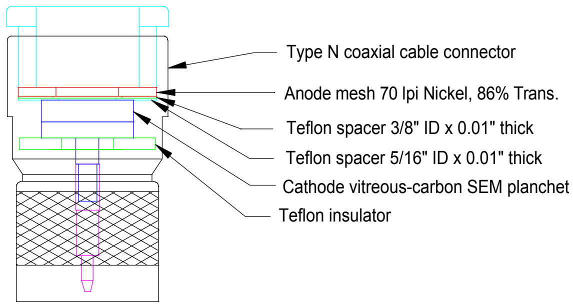

Figure 1. Los Alamos designed x-ray diode is a direct replacement for the diodes currently used on the Sandia Z-machine.

A. XRD operating limits

The maximum linear output current, in amperes, (Eq. 1) of the XRD is limited by the space-charge canceling the applied electric field [4].

$$2.33\text{x}10^{-6}\ (A_i\ V^{1.5}\ /\ d^2) \qquad (1)$$

In a real system the bias voltage is reduced due to cable impedance so the solution to Eq.1 must be iterated to obtain the maximum usable output current [5].

The signal rise time [6], in seconds, (Eq. 2) and signal fall time [7] (Eq. 3) are determined by the bias voltage, anode-cathode gap, cathode area, and cable impedance. In a real system the actual rise is dominated by the recording instrumentation and cabling. It is approximately 1.1 ns [3] in the Z-machine system.

$$3.4\text{x}10^{-6}\ (d\ /\ V^{0.5}) \qquad (2)$$
$$8.05\text{x}10^{-12}\ (Z\ A_f\ /\ d) \qquad (3)$$

For the Los Alamos detector the cathode illuminated area, $A_i=1.96\text{x}10^{-5}$ m^2, the full cathode area, $A_f=1.27\text{x}10^{-4}$ m^2, the anode-cathode gap, $d=5\text{x}10^{-4}$ m, the system impedance, Z= 50 ohms, and the bias voltage, V=1000 volts. This yields rise and fall times of 54 ps and 102 ps respectively and a cable impedance reduced output current of 4.1 amperes.

B. XRD cathode calibrations

A number of the new style vitreous-carbon and the set of used and aged cathodes have been calibrated at the National Synchrotron Light Source (NSLS) located at Brookhaven National Laboratory in Upton, New York. The absolute calibrations are accurate to about +/- 10% due to the quoted transfer standard error bars of 10%. The reproducibility of cathodes is often more important than absolute accuracy because reproducible cathodes can be replaced if damaged without affecting the instrument response. Cathodes used in the dirty environment of the Z-machine have shown response changes of up to 50% [3]. Figure 2 shows the reproducibility of some 50 vitreous-carbon cathodes used for Z-machine experiments.

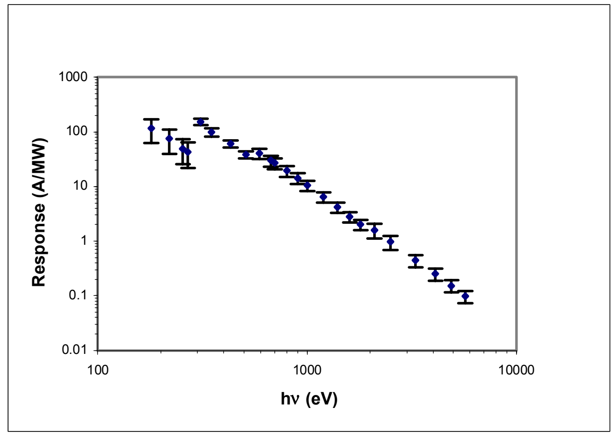

Figure 2. Reproducibility of 50 aged and used vitreous-carbon cathodes.

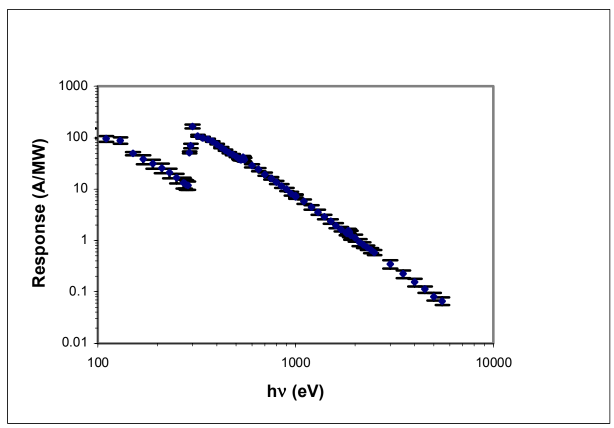

Figure 3. Reproducibility of 20 new SEM type vitreous-carbon cathodes.

Lacking any of the pristine vitreous carbon that the original SNL XRD's were constructed from it is unknown if the variations are due to intrinsic properties, aging effects, or because some of the cathodes had been used in the Z-machine. As a practical point it is irrelevant since the SEM vitreous carbon planchets are extremely reproducible and inexpensive enough (~US $70) that they could be replaced for every shot.

IV. XRD FILTERS

The standard 5-channel filter set used for our Z-machine experiments have materials and nominal areal densities shown in table 1. This set provides good spectral coverage from about 100 eV to several keV photon energies.

Filter Material	Chemical formula	Areal Density ($\mu g/cm^2$)
Kimfoil	$C_{16}H_{14}O_3$	650
Vanadium	V	490
Zinc/parylene-n	Zn / C_8H_8	570 / 55
Be/parylene-n	Be / C_8H_8	1440 / 110
Be/Vanadium	Be / V	1890 / 490

Table 1. Standard Z-experiment XRD filter set.

Filter areal densities are calculated by measuring Am^{241} alpha particle energy loss and tabulated stopping powers. By comparing several techniques, Muskalla [8] determined the alpha particle density measurement accuracy is about +/- 5%.

Filter transmission is then calculated from the measured areal density and Atomic Data Tables [9] .

Comparison of calculated transmission and synchrotron transmission measurements yields excellent agreement except in regions where known synchrotron issues exist.

Folding calculated filter transmission, nominal photocathode response, system geometry yields a table of Planckian temperature versus XRD signal. Figure 4 shows the error in temperature caused by the error in filter thickness measurement.

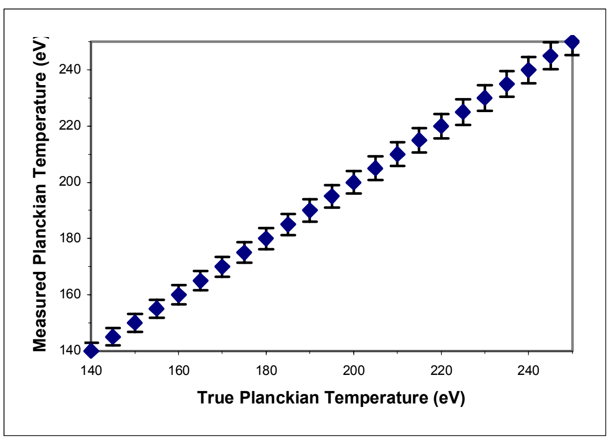

Figure 4. Error due to filter measurement error.

The errors shown are the average error of all five XRD measurements and yields a temperature measurement average error of 2.04% over the temperature range from 140 to 250 eV Planckian temperature.

V. NICKEL FILM BOLOMETERS

Bolometers operate as a total energy measuring diagnostic. The operating principle is that absorbed x-rays heat a metal film which increases its resistance proportionally to the absorbed energy [10][11] .

In practice several difficulties arise:

The specific heat of nickel is a function of temperature [12] . The resistivity of nickel is not a linear function of temperature[12]. A thin film (~ 1 micron) of nickel must be used to create observable resistance changes and reduce temperature differences caused by the differential absorption of x-rays causing most energy to be deposited near the incoming surface. However thin films of material must be mechanically supported by a substrate which can alter the temperature rise of the metal. Being a ferromagnetic material nickel exhibits a discontinuity in specific heat at the Curie temperature. And lastly, thin film nickel resistivity differs from bulk resistivity due to grain size effects [13] . Mike Cuneo, at Sandia, has made attempts to account for the specific heat and resistivity non-linearities with some success at low power levels. However, at the higher powers present in our experiments we have been unable to resolve differences in bolometer versus XRD measured source temperatures.

VI. POWER MEASUREMENTS

Inconsistencies have appeared in powers derived from different measuring instruments. Early data in figure 5 shows large differences in bolometrically (squares and diamonds) derived power and the x-ray power deduced from an unfold of the five XRD channels (data O).

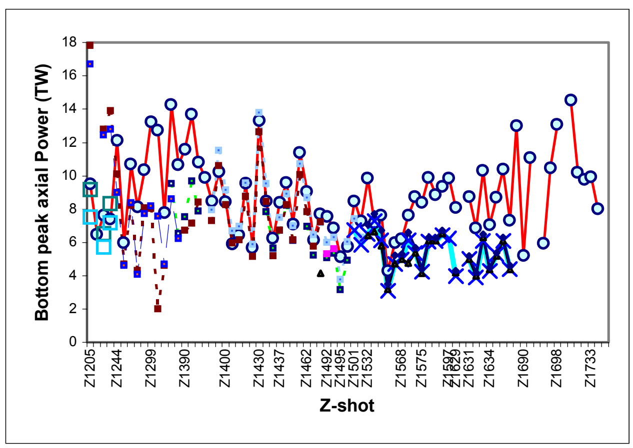

Figure 5. XRD unfold and bolometric powers for 75 Z-machine shots.

After carefully tracking the XRD filters and detector we obtained good agreement for a long period. However, more recent data again indicates disagreement. Radiographic data from our experiments indicates the derived XRD power is more likely correct but the cause of anomalously low powers from the bolometers remains unresolved. Note that even though the bolometers

disagree with the XRD's they generally agree with each other within about 10%.

It is possible that the high-power Z-shots are overheating the surface of the bolometer element driving it into a non-linear region thereby invalidating the +/- 11% accuracy observed by Spielman [11] . Hydro-code 1-d calculation of the behavior of the bolometer surface has so far been inconclusive. A typical z-shot will deposit a peak of 80 kW in the top 10 nm of the nickel bolometer element. To maintain its linearity the thermal conductivity must be high enough to conduct this heat into the deeper layers rapidly enough to prevent melting.

VII. SUMMARY

Used vitreous-carbon XRD's yield absolute power measurement accuracy of +/- 20%[3] provided the XRD surface hasn't been 'damaged'. New SEM planchet vitreous-carbon cathode XRD's can improve the absolute accuracy to +/- 12-15%. New SEM cathode XRD's can measure source power reproducibility to about +/- 6%. The low cost and good reproducibility of the SEM type cathodes allows the cathodes to be replaced on every shot so Z-machine contamination problems can be eliminated.

Although identical nickel foil bolometers usually agree within 10% the inferred absolute energy measured may incorrect due to non-linear heating effects. Bolometer issues may be addressed by placing a thin-film filter in front of the bolometer element to remove the soft x-rays or by tilting the element with respect to the incoming x-rays to reduce the energy density on the element.

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